Biological Conservation 229 (2019) 14–25

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Coral restoration: Socio-ecological perspectives of benefits and limitations

Margaux Y. Hein[a,b,*], Alastair Birtles[a], Bette L. Willis[a,b], Naomi Gardiner[a], Roger Beeden[c], Nadine A. Marshall[d]

[a] College of Science and Engineering, James Cook University, Townsville, Queensland, 4811, Australia
[b] Australian Research Council (ARC) Centre of Excellence for Coral Reef Studies, Townsville, Queensland, 4811, Australia
[c] Great Barrier Reef Marine Park Authority, Townsville, Queensland, 4810, Australia
[d] CSIRO Land and Water, ATSIP Building #145, James Cook University, Townsville, Queensland, 4811, Australia

ARTICLE INFO

Keywords:
Coral restoration
Reef resilience
Sustainability
Socio-ecological systems

ABSTRACT

Coral restoration is increasingly used globally as a management tool to minimize accelerating coral reef degradation resulting from climate change. Yet, the science of coral restoration is still very focused on ecological and technical considerations, impeding the understanding of how coral restoration can be used to improve reef resilience in the context of socio-ecological systems. Here, we visited four well-established coral restoration projects in different regions of the world (Thailand, Maldives, Florida Keys, and US Virgin Islands), and conducted key-informant interviews to characterize local stakeholder's perceptions of the key benefits and limitations associated with restoration efforts. Our results reveal that perceptions around coral reef restoration encompass far more than ecological considerations, and include all four dimensions of sustainability: ecological, social, economic, and governance, suggesting that effective coral restoration should be guided by the principles of sustainability science. Socio-cultural benefits were the most frequently mentioned (72.4% of all respondents), while technical problems were the most common theme for limitations of coral restoration efforts (58.3% of the respondents). Participants also revealed some key points likely to improve the outcomes of coral restoration efforts such as the need to better embrace socio-cultural dimensions in goal setting, evaluate ecological outcomes more broadly, secure long-term funding and improve management and logistics of day to day practices. While we identify several important limitations of coral reef restoration, particularly around amateur workforces and limited involvement of local communities, our results suggest that coral restoration can be used as a powerful conservation education tool to provide hope, enhance agency, promote stewardship and strengthen coral reef conservation strategies.

1. Introduction

Ecological restoration is increasingly used around the globe to address the dramatic declines in the extent and function of many ecosystems due to rising anthropogenic and climate-change driven impacts (Young, 2000; Aronson and Alexander, 2013; Perring et al., 2015). In a sense, the rise of ecological restoration in the last 60 years represents a shift in the history of humanity's relationship with nature from intensive resource exploitation to resource conservation. This paradigm shift may be driven by a cultural norm and social awareness about the loss of species and habitats due to resource exploitation, as well as the recognition that nature is providing humanity with many “free” ecosystem services (Millennium Ecosystem Assessment (MA), 2005). Yet, as we realise the importance of many ecosystems services for our own wellbeing and liveability, we are increasingly seeing these services diminish, and in some cases, vanish. In response, restoring ecosystems has recently become central to international conservation goals, especially in the face of climate change-related disturbances (Aronson and Alexander, 2013; Suding et al., 2015). Rising atmospheric and oceanic temperatures, as well as increases in carbon dioxide have already been shown to seriously degrade ecosystem function globally. For example, global temperature increases associated with climate change have been shown to impact the timing of species' life events such as migration and reproductive cycles (e.g. Both et al., 2006), leading to mismatches, altering species demographics and survival (Walther et al., 2002).

Marine ecosystems and coral reefs are particularly affected by climate change (Hoegh-Guldberg and Bruno, 2010). In just two years, the Great Barrier Reef in Australia has lost over 30% of its coral cover due to a mass coral bleaching event attributed to abnormally high sea surface temperatures (Hughes et al., 2017, 2018). Similar catastrophic

* Corresponding author at: College of Science and Engineering, James Cook University, Townsville, Queensland, 4811, Australia.
E-mail address: margaux.hein@my.jcu.edu.au (M.Y. Hein).

https://doi.org/10.1016/j.biocon.2018.11.014
Received 11 June 2018; Received in revised form 5 November 2018; Accepted 10 November 2018
Available online 17 November 2018
0006-3207/ © 2018 Elsevier Ltd. All rights reserved.

declines in coral cover are occurring globally (De'ath et al., 2012; Jackson et al., 2014; Eakin et al., 2016), and are exacerbated by other disturbances to reefs such as pollution, storms, crown-of-thorns starfish outbreaks, and coral diseases (Alvarez-Filip et al., 2009; De'ath et al., 2012; Wolff et al., 2018), leading to local and global changes in reefs community functions and structures (Knowlton and Jackson, 2008; Hughes et al., 2018). Such rapid changes are cause for great concern since coral reefs provide a wide range of valuable ecosystem services to local and global communities such as food security, commercial opportunities, coastal protection, and strong cultural values (Moberg and Folke, 1999; MA, 2005). Accelerated climate-change and human pressures on coral reefs have led to a rapid rise in advocacy, and deployment of intervention strategies such as coral restoration are increasingly advocated to protect what reefs and associated reef-ecosystem functions we have left (Anthony et al., 2017; Darling and Côté, 2018). Yet, in contrast to other ecosystems such as forests and wetlands, coral restoration is still in its infancy, and very much focused on small scale, short-term technicalities such as growth and survival characteristics of coral fragments post-transplantation (Hein et al., 2017). While these are necessary for improving restoration designs, critical information as to whether coral restoration can successfully increase reef resilience is currently lacking.

Reef resilience is increasingly recognised as the main objective of reef ecosystem management (Maynard et al., 2015, 2017). Defined as the capacity of the reef ecosystem to resist and/or recover from acute and chronic disturbances (e.g. Mumby et al., 2007; Hughes et al., 2010), resilience typically encompasses ecological and social dimensions (Cumming et al., 2005; Folke, 2006). The social dimension of resilience recognises humans as an integral part of ecosystem processes where the positive and negative impacts of degrading environments on social systems are considered as part of a social-ecological feedback loop (Glaser, 2006; Marshall and Marshall, 2007). Societies, especially those with low socio-ecological resilience (Marshall et al., 2013), also play a critical role in accelerating the declines of coral reefs worldwide with a range of anthropogenic pressures such as increased coastal development leading to increased sedimentation (McCulloch et al., 2003), coral diseases (Haapkylä et al., 2011), and decrease in water quality (Brodie et al., 2012). Increasingly, ecosystem management strategies are focused on socio-ecological systems rather than ecological systems alone, enabling better understanding of the socio-cultural, economic, and institutional forces driving changes (Folke, 2006). The socio-ecological view of resilience thus integrates society's capacity to adapt and change as well as considering disturbances as opportunities for adaptive change (Berkes et al., 2003; Folke, 2006).

Socio-ecological systems are complex, and the insights that are derived from studying them depend on the view they are studied from (i.e. eco-centric versus anthropocentric) (Glaser, 2006). One framework, the “prism of sustainability” by Valentin and Spangenberg (2000), integrates four dimensions of socio-ecological systems: ecological (i.e. the biological system), social (i.e. people's involvement and support), economic (i.e. sustained funding and potential economic benefits), and governance (i.e. project management, institutional support and any pertinent laws or regulations). These four dimensions are increasingly integrated in the goals and definition of ecological restoration (Jellinek et al., 2014, Perring et al., 2015, Martin, 2017), yet they are virtually absent from the coral restoration literature (Hein et al., 2017). The strong ecological focus of coral restoration to date may be limiting the full suite of coral restoration learnings that could enhance coral restoration strategies and practices, and their resilience benefits.

The human dimension is particularly relevant to coral restoration since people are involved in all stages of the restoration process, from design to execution and monitoring. Involvement of volunteers and citizen scientists in restoration efforts has the potential to improve local and global stewardship of reef resources (Hungerford and Volk, 1990; Elwood et al., 2017; Dean et al., 2018). Volunteers can also help to increase the capacity of coral restoration efforts both physically and financially, therefore widening the impact scale of restoration (Dhillion et al., 2004; Tulloch et al., 2013). Benefits of restoration are also ultimately for people, in the form of sustained and/or increased ecosystem services (Martin, 2017). Such benefits can only be understood by looking at coral restoration success from a socio-ecological perspective. Socio-cultural benefits of coral restoration are likely to include the spectrum of ecosystem services provided by coral reefs such as the provision of alternative livelihood opportunities, increased educational opportunities, building stewardship, maintenance of wellbeing, identity, place attachment, aesthetics and pride around resource condition (Kittinger et al., 2012; Frey and Berkes, 2014; Hesley et al., 2017; Marshall et al., 2017). Economic considerations are also essential to better appreciate the full range of costs and benefits associated with coral restoration (Bayraktarov et al., 2015; Kittinger et al., 2016). Finally, governance considerations are central to the adaptive potential of coral restoration efforts. Restoring agency around the use and management of natural resources (i.e. empowering people in decision-making) is likely to be an important benefit of coral reef restoration, potentially increasing the capacity to better understand coral reef decline and its management (Bennett et al., 2016). Reef restoration managers not only need to understand if their coral out-plants are growing, but also the extent to which their work is meeting the public's expectations, as public support for the project is paramount to secure long-term support (Bennett et al., 2016; Sterling et al., 2017). There is thus a pressing need to increase our understanding of the strengths and limitations of current coral restoration practices to enhance management and build best-practice frameworks to guide their use as socio-ecological conservation strategies.

The aims of this study are to identify and document the potential benefits and limitations of contemporary coral restoration at a social-ecological scale to inform the current debate around the value of coral restoration, and the extent to which government and community investment might occur. We address these aims through the analysis of data from targeted key-informant interviews at four well-established coral restoration projects around the world.

2. Method

Face-to-face key-informant interviews were conducted at four well established coral restoration projects around the world: New Heaven Reef Conservation Program (Koh Tao, Thailand), Reefscapers (Landaa Giraavaru, Maldives), the Coral Restoration Foundation (Florida Keys, USA), and The Nature Conservancy Caribbean Program (St Croix, US Virgin Island) (Table A, Appendix A, Section 1). All four projects have been in operation for between 8 and 12 years and are recognised as successful in the coral restoration community. These four projects also vary in terms of their specific objectives, methods of outreach and sources of funding (Table A, Appendix A, Section 1), therefore providing a variety of contexts for this study. In order to identify the benefits and limitations of coral restoration globally, thirty respondents were interviewed at each location giving a total of 120 interviews. The selection of respondents followed a snowball sampling design after initial discussions with local project managers. Interviewees were stratified across a large range of stakeholders in terms of age, gender, roles (e.g. restoration project staff, dive industry personnel, members of the local community etc.) to increase variation and provide a breadth of perspectives (Table B, Appendix A, Section 1).

Interviews were conducted in English and typically lasted between 15 min and 1 h. English was not a limiting factor, even in Koh Tao and Landaa Giraavaru since both locations are heavily reliant on English-speaking tourism. All interviews were audio-recorded and later transcribed. Data were analyzed using NVivo (Version 11.4.2 (2081)), and the statistical software R (version 3.4.1).

2.1. Interview design, administration and analysis

A copy of the interview questionnaire is available in the Supplementary materials (Appendix A, Section 2). In brief, interview questions were organized into five sections: (1) demographics, (2) experience with coral reefs, (3) benefits and limitations of the coral restoration efforts, (4) financial aspects, and (5) overall opinions on the coral restoration project. In the first two sections, respondents were asked a series of closed questions about how long they had been in the given location, their experience as divers and snorkelers, as well as scalar questions in which they were asked to rate attributes of the local reefs in terms of beauty, coral and fish abundance and diversity. Responses were recorded on a scale of one to ten, where one was "extremely bad" and ten was "extremely good". Prompts and flashcards were used to guide the respondents. For example, scales from one to ten were presented on a piece of paper to provide some visual reference for the respondent. The third section consisted of open-ended questions about both the benefits and limitations of coral restoration. These questions enabled respondents to speak freely about their perspectives and thus increase the breadth and depth of understanding. The last two sections included a mix of closed, open-ended, and scalar questions to guide the conversation towards more specific aspects of the restoration efforts such as financial aspects and long-term perspectives. The initial version of the survey was pilot tested with colleagues and willing project members for the purposes of ensuring that the survey questions were unambiguous, easy to understand, and easy enough to respond to.

To ensure anonymity, each respondent was given a code based on the location, as well as their role, and a number from 1 to 30 assigned in alphabetical order. Codes for locations were as follows: Koh Tao (KT), Landaa Giraavaru (LG), Florida Keys (FK), and St Croix (SC). Eight groups of respondents were identified based on their roles: project staff (PS), project interns (PI), project volunteers (PV), dive industry personnel (DI), conservation professional (CP), tourism industry (TI), fishermen (FI), and local community (LO). "Project staff" were people paid for their involvement in the restoration efforts; "project interns" were long-term volunteers, typically involved in the restoration efforts for two to three months; "project volunteers" were typically involved in the restoration efforts for one day to two weeks; "dive industry" were people involved in diving activities (e.g. dive shop owners, dive instructors, etc.) at the specific location; "conservation professionals" were people involved more broadly in other conservation actions other than the specific coral restoration project, "tourism industry" were people involved in tourism activities (e.g. watersport industry); "fishermen" were people involved in commercial or recreational fishing activities, and "local community" included other people from the community living at the specific location.

These eight groups were then categorized as either "involved" for groups of people involved first-hand in the restoration efforts (project staff, project interns, project volunteers, and conservation practitioners), and "others" (dive industry personnel, tourism industry, fishermen, and local community).

2.2. Identifying the benefits associated with coral reef restoration

Benefits of coral restoration were identified from responses to the question: "What do you think are the three best things about the coral restoration program?" The question used the term "best things" as a colloquial way to engage respondents to discuss the benefits of the projects. Answers to this question were coded into themes, sub-themes and categories (coding groups). A content analysis was performed by the principal investigator to uncover the main themes from the responses. These themes were then checked with co-investigators to ensure that each was as independent as possible, and that all responses were accounted for. Further content analysis enabled sub-themes and categories to be identified. Coding was an iterative process, and co-investigators were repeatedly consulted to ensure homogenous interpretation and description of each coding group. The total number of sources (i.e. number of respondents), and references (i.e. numbers of citations) were also recorded for each coding group across all respondents. Finally, each coding group was analyzed per groups of respondents, as well as across all four locations.

2.3. Identifying limitations of coral reef restoration

Limitations of coral restoration were identified from responses to the question: "What do you think are the three greatest problems about the coral restoration program?". Here, the term "greatest problems" was used as a colloquial way to engage respondents in discussion about the limitations of the projects. Steps described above for iterative content analysis were repeated.

Coding groups, and groups of respondents were analyzed as fixed factors. A variety of models were tested, including ones where explanatory variables were treated as having either additive or multiplicative effects, and where data were log-transformed. AICc model selection was used to select the model explaining the greatest variation in the data, i.e., the model having the lowest AICc score. Assumptions for model validity were checked through QQ plots and residual plots. When tests failed to meet the assumptions of a Gaussian distribution after log-transformation, non-parametric Kruskal-Wallis tests were applied. When applicable, post-hoc Tukey's HSD tests were also applied to tease out differences among treatments and sites.

3. Results

A total of 120 participants responded to the interviews, with 116 participants responding to the "benefits" question, and 96 participants responding to the "limitations" question. Respondents who replied "*I don't know*" were included in the analysis.

For the benefits, five themes emerged from the initial content analysis: 1. Socio-cultural benefits, 2. Ecological benefits, 3. Project appreciation, 4. Positive experiences, and 5. Economic benefits (Fig. 1; Table C, Appendix B). Six themes emerged for the limitations: 1. Technical limitations, 2. Management limitations, 3. Ecological limitations, 4. Restoration limitations, 5. Staff limitations, 6. Legislative limitations (Fig. 1; Table D, Appendix B). Descriptions of each theme are given below (Sections 3.1 and 3.2).

A total of 29 sub-themes were identified as benefits, and 34 sub-themes as limitations of coral restoration efforts across the different themes (Fig. 1; Tables C, D, Appendix B). The most frequently mentioned sub-theme describing benefits were 'ecosystem function' under the theme 'ecological benefits', while the most mentioned sub-theme for limitations was 'lack of capacity' under the theme 'technical limitations' (Fig. 1). The least mentioned benefits of coral restoration were 'food security', 'legislative support', and 'legacy'. 'lack of regulations and enforcement', 'inadequate government funding', 'over-ambitious', and 'limited site-accessibility' were the least mentioned sub-themes for the limitations (Fig. 1).

3.1. Benefits

Among the five over-arching themes identified for benefits of coral restoration, the themes 'socio-cultural benefits' and 'ecological benefits' were significantly more frequently mentioned than the other themes (see p-values in Table 1). 'Socio-cultural benefits' was the most frequently mentioned theme, with 72.4% (n = 84 sources) of the respondents mentioning a total of 183 items that were grouped under that category (Table C, Appendix B), followed by 'ecological benefits' (68.9% of the respondents, n = 80 sources), 'project appreciation' (31.9% of the respondents, n = 37 sources), 'positive experience' (30.2% of the respondents, n = 35 sources) and 'economic benefits' (18.9% of the respondents, n = 22 sources).

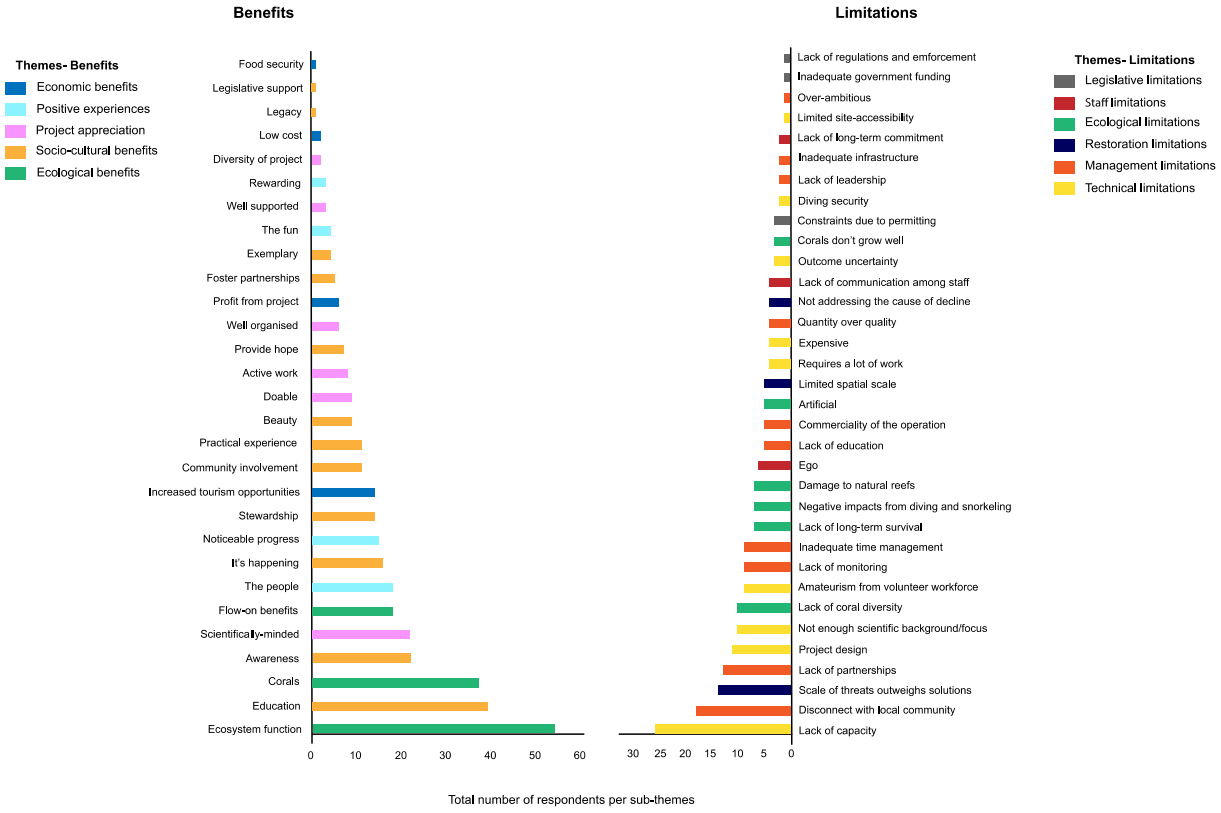

Fig. 1. Total number of respondents mentioning each sub-theme for both benefits (n = 116 respondents) and limitations (n = 96 respondents) of coral restoration efforts.

Table 1
Tukey's contrasts multiple comparisons with adjusted p-values for the proportion of responses per theme of benefits.

Comparison	p. adjusted
Ecological benefits – project appreciation	**0.0014***
Economic benefits – project appreciation	0.9228
Positive experience – project appreciation	0.9997
Socio-cultural benefits – project appreciation	**0.0028***
Economic benefits – ecological benefits	< **0.001***
Positive experience– ecological benefits	< **0.001***
Socio-cultural benefits – ecological benefits	0.9998
Positive experience – economic benefits	0.9684
Socio-cultural benefits – economic benefits	< **0.001***
Socio-cultural benefits – positive experience	**0.0013***

* Indicates significance.

3.1.1. Socio-cultural benefits

The theme 'socio-cultural benefits' referred to responses attached to the human dimension of the restoration efforts and benefits at the scale of the local community. Responses under the theme 'socio-cultural benefits' were provided by 72.4% of the respondents at all four locations (Table C, Appendix B). Twelve sub-themes were identified ranging from 'education' (n = 32 sources), to 'community involvement' (n = 11 sources), and 'beauty' (n = 9 sources) illustrating the broad nature of potential socio-cultural benefits linked to coral restoration efforts. The sub-theme 'education' was also the second most mentioned benefit of coral restoration (Fig. 1). 'Education' was linked to increased awareness of coral reefs and associated threats and solutions. For example, one respondent suggested:

"*It's brought a lot of public awareness. People are a lot more aware of the problems going on out there when we try to talk about what we're trying to do to fix it.*"

FK12CP

Another respondent described possible solutions:

"*The hands-on part as well. You feel like you're actually out there, helping out, making a difference,*"

KT12PV

and encouraged stewardship:

"*Make people learn and feel like they protect the reef.*"

KT02LO

The sub-theme 'community involvement' described hands-on, practical experience with the idea that it is not just about getting people involved in coral restoration, but also about giving them practical involvement:

"*It's good to have guests involved that way and have them do it.*"

LG05DI

The sub-theme 'It's happening' included responses from 16 sources across all four locations. Respondents strongly valued the mere fact that coral restoration efforts were in place (i.e that something was being done to address the threats to coral reef):

"*The fact that there is an effort going in to actually try and restore the reef, which I think is very important.*"

LG04PS

This concept was also linked to the sub-themes 'Provide hope' (n = 7 sources) and 'Legacy' (n = 1 source) that reflect that not all is lost, and that coral restoration is bringing some optimism for the future of coral reefs:

"*It's providing a hopeful message about the future that while we are being destructive in certain ways, we also have it in our own hands to be able to fix things for the future.*"

FK03PI

3.1.2. Ecological benefits

The theme 'ecological benefits' referred to responses attached to the reef dimension of the restoration efforts. Responses under the theme 'ecological benefits' were broadly categorized in three sub-themes: 'ecosystem function' (n = 54 sources), 'corals' (n = 37 sources), and 'flow-on benefits' (n = 18 sources) (Table C, Appendix B). 'flow on benefits' referred to projects or actions that emanate from the restoration program and convey further benefits for the reef ecosystem. Participants thus recognised ecological benefits at various scales with flow-on benefits from the scale of the corals used for restoration:

"*Bringing back Acropora to reefs that no longer have it*,"

FK12CP

to the scale of the reef ecosystem:

"*It's going to attract more fish life, diversity, it's going to help in the health in general, and help the corals grow and diversify*,"

FK24DI

and to the scale of ecosystem services (e.g. coastal protection):

"*We have a lot of erosion and you know it helps out in this way*."

LG12TI

The sub-theme 'ecosystem function' was the most mentioned benefit of coral restoration (Fig. 1), reinforcing the idea that respondents recognise that coral restoration is not just about planting corals back onto the reef, but that the efforts have implications at the scale of the reef ecosystem.

3.1.3. Project appreciation

Responses coded under this theme referred to positive links with a coral restoration project, rather than benefits flowing from the coral restoration efforts. Participants highlighted both the importance given to the role of science as well as to the logistics of the restoration efforts. For example, the sub-theme 'scientifically minded' ranked fifth as the most mentioned benefit (n = 22 sources, Fig. 1). 'Science' (n = 13 sources) was also mentioned as a way to improve existing methods:

"*We can give corals to other researchers to do research work that may inform restoration*,"

FK05CP

and to legitimize the effort:

"*It's done by marine biologists - I believe what they are doing. They know where to collect the corals, they don't just go and break things off*."

LG10TI

Respondents also recognised the importance of logistics of the restoration operation with sub-themes like 'doable' (n = 9 sources), 'well-organized' (n = 6 sources), and 'well-supported' (n = 3 sources) (Table C, Appendix B), highlighting the importance of good management:

"*They are organized, you know, it's been easy for us to learn because it's pretty simple how you go through about the day*."

FK29PI

Participants also appreciated the feasibility of the restoration efforts:

"*It's really easy. You might have the opinion that it's complicated but it's actually quite simple. It's mostly underwater gardening*."

KT09PS

3.1.4. Positive experiences

Responses under the theme 'positive experiences' also related to the coral restoration projects rather than outcomes of the restoration effort. The sub-theme 'people' (n = 18 sources) revealed that the people involved in the project played a major role in participants' experiences. For example, respondents noted positives linked to dedication:

"*I get to be taught by such educated and passionate people. The staff here I've learned so much from and I've been really inspired by*,"

KT24PI

As well as to the diversity of people involved:

"*Meeting so many people from all around. Everyone from different experiences and we all learn from one another*,"

KT26PS

The sub-theme 'rewarding' (n = 3 sources) was also related to the sub-theme 'noticeable progress' (n = 15 sources):

"*I think just really satisfying to see the corals and see that you're making a difference*."

KT12PV

These sub-themes are also linked to socio-cultural benefits of providing hope through tangible progress:

"*There's a full circle story. You can tell that you can actually see the impact*."

SC12PS

3.1.5. Economic benefits

The theme 'economic benefits' referred to positive economic revenues from the restoration effort. Economic benefits were the least mentioned benefits among all five themes. The low emphasis of potential economic revenues from the project (n = 6 sources) suggests that economic profits are not the primary motivation of restoration practitioners. Yet, some participants recognised that bringing back corals on the reefs could benefit the local economy, especially for responses coded under 'increased tourism opportunities' (n = 14 sources):

"*Bring back the coral life which will bring back the marine life which will bring back the tourists*."

FK09TI

3.1.6. Location and role specific differences in responses for benefits

Responses varied across the four different projects surveyed (Fig. 2A) as well as across the roles of the respondents (Fig. 2B, C). For example, while perceptions of socio-cultural benefits were consistently brought up by over 60% of total respondents at all four locations, they were most strongly acknowledged by people directly involved in the restoration efforts (Kruskal-Wallis, chi-squared = 5.4, df1 = p = 0.02, Fig. 2C). People involved in the restoration efforts also mentioned benefits under the themes 'positive experience', and 'project appreciation' significantly more often than the other groups (Kruskal-Wallis, positive experience: chi-squared = 5.3, df1 = p = 0.02; project appreciation: chi-squared = 5.4, df1 = p = 0.02, Fig. 2C).

Ecological benefits were also recognised widely across all four locations, but different sub-themes were brought up depending on the type of projects. In St Croix and the Florida Keys, responses were mostly focused on species conservation (Table C, Appendix B).

On the other hand, the notion that restoration efforts create new reef habitat was only brought up in Koh Tao and Landaa Giraavaru (Table C, Appendix B), which are the only two sites to use artificial structures for restoration. In Koh Tao where restoration efforts are part of a wider conservation program, responses were also more focused on flow-on benefits and actions that reduce further damage to reef ecosystems. In Landaa Giraavaru, responses were more focused on coastal protection (Table C, Appendix B), which echoes the dire situation of the Maldives Archipelago which is composed of a low-lying island system that is seriously threatened by sea level rise.

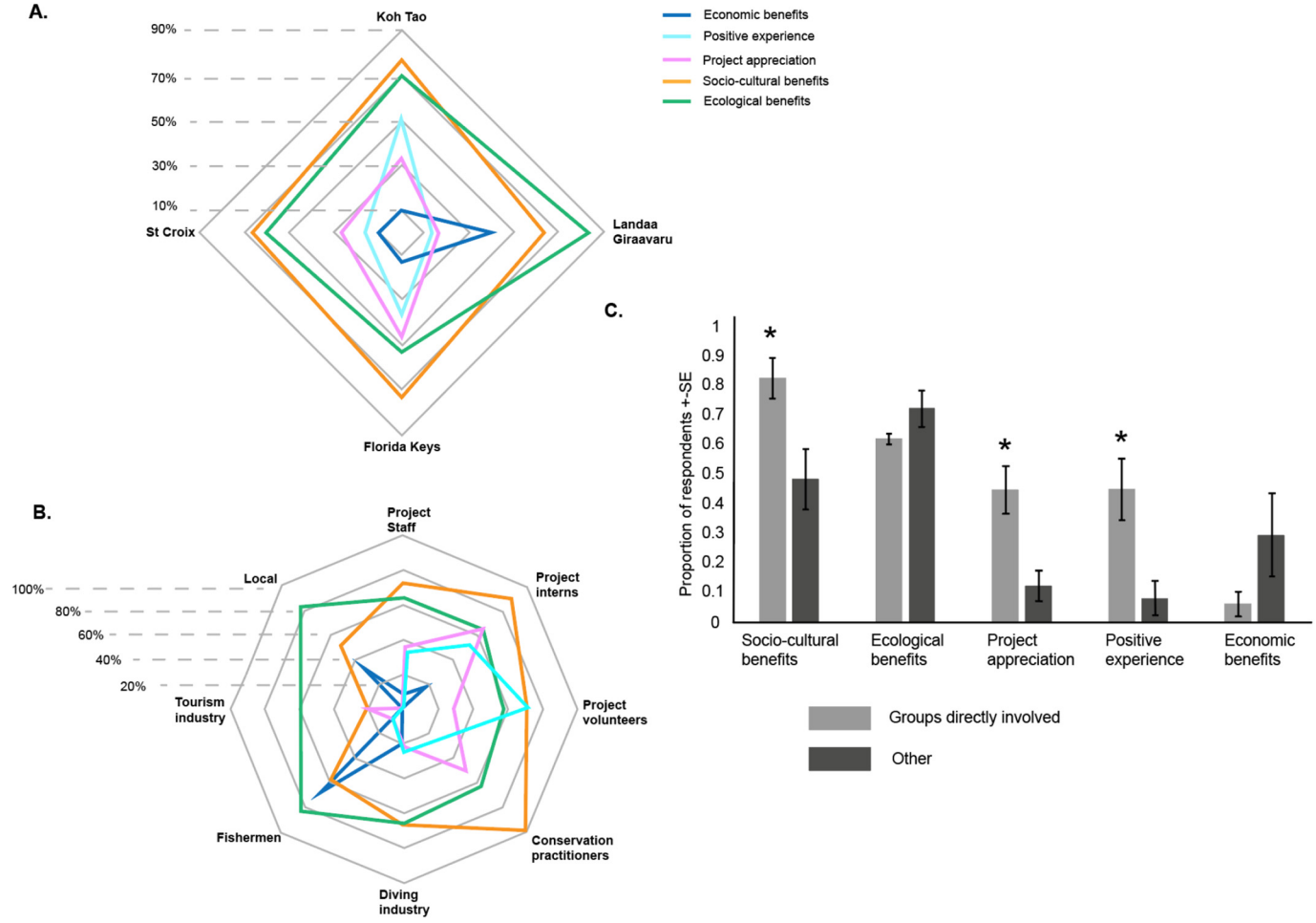

Fig. 2. Variation in the proportion of responses for themes of benefits among all four locations (n = 30 respondents per location) (A), group of stakeholders (B), and between groups of people involved directly in the efforts (n = 60 respondents) and others (n = 60 respondents) (C). * indicates significance.

Ecological benefits were mentioned by all types of groups of respondents with no significant difference between groups of people directly involved in the restoration efforts and others (Kruskal-Wallis, chi-squared = 2.1, df1 = p = 0.14, Fig. 2C), suggesting that coral restoration is perceived as having ecological benefits by all type of stakeholders, and further echoes the flow-on benefits of education through the local community. Responses within the theme 'economic benefits' were most prevalent in Landaa Giraavaru which was the most business-oriented project as part of a luxury resort hotel complex, but even there, they were limited to < 50% of the respondents (Fig. 2B). Responses under that theme also varied among groups of respondents, being most often mentioned by locals and the tourism industry, and least often brought up by project staff and conservation professionals (Fig. 2). Locals and tourism industry were also the groups that most mentioned ecological benefits indicating that these people not only believe in the ecological benefits of coral restoration but also believe that bringing corals back will benefit the local economy. There was also a lower emphasis on economic benefits by project staff and conservation professionals (Fig. 2B).

Table 2
Tukey's contrasts multiple comparisons with adjusted p-values for the proportion of responses per theme of limitations.

Comparison	p. adjusted
Governance – ecological	0.0976
Management – ecological	0.9962
Restoration – ecological	0.5604
Staff – ecological	0.0698
Technical – ecological	0.0885
Management – governance	**0.0238***
Restoration – governance	0.9358
Staff – governance	1.0000
Technical – governance	< **0.001***
Restoration – management	0.2577
Staff – management	**0.0157***
Technical – management	0.2697
Staff – restoration	0.8930
Technical - restoration	< **0.001***
Staff - technical	< **0.001***

* Indicate significance.

3.2. Limitations

Among the six themes identified for the limitations of coral restoration, the themes 'technical limitations' and 'management limitations' were significantly more frequently mentioned than the other themes (see p-values in Table 2). The theme 'technical limitations' was the most common theme, mentioned by 58.3% of the respondents (n = 56 sources), followed by 'management limitations' (42.7% of the respondents, n = 42 sources), 'ecological limitations' (34.3% of the respondents, n = 33 sources), 'restoration limitation' (19.8% of the respondents, n = 19 sources), 'staff limitations' (11.4% of the respondents, n = 11 sources), and 'legislative limitations' (5.2% of the respondents, n = 5 sources) (Table D, Appendix B).

3.2.1. Technical limitations

The theme 'technical limitations' referred to problems associated with the logistics of the restoration efforts. Several technical limitations were identified (Table D, Appendix B), and 'lack of capacity' (n = 26 sources) was most talked about. For example, participants recognised the 'limited number of people involved' (=15 sources) and the 'lack of funding' (n = 14 sources) as major limitations:

"*We don't have enough people do all that we want to do of course*"
FK18PS

"*The funding is less than a level necessary to do the work properly*."
SC01PS

Participants also identified technical limitations linked to the projects' designs. For example, they raised issues linked to the 'material used for restoration' (n = 5 sources) or with the 'location of transplantation' (n = 3 sources):

"*I think one of the challenges with restoration at the moment is finding a material that is as strong as concrete but doesn't have the same environmental problems*"
KT06PS

"*Where the corals are actually being planted. I think they could do a better job with that.*"
FK15PS

In particular, some respondents criticised the lack of science behind the efforts (n = 10 sources):

"*It would be nice if there was a little more science embedded in the methodology*"
SC14PI

Finally, an important technical limitation was linked to potential damage caused by untrained volunteer workforce (n = 9 sources):

"*You go with* [*the*] *new student you see them struggling and that results in them doing a bit of a lousy job. The fragments might not be well secured and might fall off in the future.*"
KT07PI

3.2.2. Management limitations

The theme 'management limitations' referred to problems associated with decision-making in the execution of the restoration efforts. The most common limitation under that theme was linked to disconnects between the coral restoration efforts and the local community (n = 18 sources). This disconnect was linked to 'lack of community awareness' of the project (n = 7 sources):

"*I don't know that we are spread through the community very effectively*."
SC18PS

Some respondents attributed the 'lack of community awareness' to a 'lack of communication with the public' (n = 14 sources):

"There is very limited awareness of what they are doing, how they are doing it, everything."
SC05DI

Beyond members of the local community, respondents also criticised 'lack of partnerships' (n = 13 sources) with other dive schools, other local or international conservation practitioners:

"*The term partnership is too loose and there should be more of a coordinated effort if it's going to be a population enhancement project.*"
FK12CP

Other management limitations were again linked to logistical limitations. For example, respondents criticised the time-management of volunteers, staff and interns, which was reinforced by criticisms of the limited time allocated to the monitoring of the restoration efforts:

"*Sometimes as an intern we tend to sit around and do nothing in the morning*"
KT24PI

"*Long-term and large-scale monitoring is probably our biggest issue. Because, it's just hard to understand the success*."
FK05CP

3.2.3. Ecological limitations

The theme 'ecological limitations' included responses that referred to unsatisfactory ecological outcomes from the restoration efforts. Several ecological limitations were raised by the participants with the 'lack of coral diversity' used in the restoration efforts raised as the most prevalent issue (n = 10 sources, Table D, Appendix B):

"*We've only been focusing on Elkhorn and Staghorn corals whereas a healthy reef has a lot more diversity than that.*"
SC18PS

Other limitations included poor health of the coral fragments used for restoration through 'limited long-term survival' post-transplantation (n = 7 sources) or 'negative impacts from diving and snorkelling' at the restoration sites (n = 7 sources):

"*A lot of fragments do die.*"
LG11PS

"*A lot of the areas are well dived and that can actually affect the coral.*"
SC30FI

Finally, some participants mentioned potential 'damage to natural reef' through detrimental ecological effects of coral restoration on wild coral colonies (n = 7 sources):

"*It could actually damage the parent colonies from where they are getting the pieces of corals*."
LG20LO

3.2.4. Restoration limitations

Responses under the theme 'restoration limitations' referred to limitations of coral restoration efforts as a reef management strategy (Table D, Appendix B). The main criticism was that the scale of the outside threats to the reef ecosystem outweighs the scale of solution (n = 14 sources):

"*The problem is global and this is just one local solution. We put corals back on the reef, but it doesn't stop bleaching or tourism and people who would go break it.*"
KT01PI

Other criticisms included the limited spatial scale of the potential benefits of coral restoration (n = 5 sources), as well as the limited capacity of coral restoration to address the cause of reef declines (n = 4 sources):

"*It's small scale - we help a few reefs on Koh Tao and it's not enough at all*"
KT01PI

"*It's like using duct tape over something that's broken. It doesn't fix the problem.*"
FK14PS

3.2.5. Staff limitations

The theme 'staff limitations' was associated with internal issues within the restoration programs. Internal issues within the coral restoration groups were mostly driven by 'ego' (n = 6 sources) and 'lack of communication among staff' members (n = 4 sources), and

eventually affected the efficiency of the restoration work negatively:

"*There is too much turf battles and pride and less teamwork that there needs to be.*"

FK28PS

"*The information one person gets doesn't fan out to all the other people that need it. And you're always hunting people down to ask some questions.*"

FK11PS

3.2.6. Legislative limitations

The theme 'legislative limitations' referred to unsatisfactory support from local and national governments, and permit limitations. Legislative limitations were only raised by five participants across all four projects surveyed. 'Constraints due to permitting' was the most prevalent criticism (n = 3 sources, Table D, Appendix B). For example, participants raised the issue that permit limitations often overruled common-sense in day-to-day operations of the restoration efforts, thereby negatively affecting logistics and efficiency:

"*Permitting requirements which are very specific, and tedious, and time consuming.*"

FK14PS

Other criticisms included inadequate funding support from the government (n = 1 source), as well as lack of enforcement and regulations limiting their potential to scale-up their impacts beyond the localised restoration efforts (n = 1 source):

"*The new regulations from last year - nothing is being enforced. We're working on trying to get things enforced, but it's difficult, it's not easy.*"

KT09PS

3.2.7. Location and role specific differences as limitations

Responses for limitations also varied by location (Fig. 3A), and across different groups of respondents (Fig. 3B, C). For example, 'technical limitations' were the most common limitations (over 50% of the respondents) brought up in both Koh Tao and the Florida Keys, while 'ecological limitations' were the most common limitations in Landaa Giraavaru (approximately 50%, Fig. 3A). In St Croix however, 'technical' and 'management' limitations were both mentioned by about 40% of the respondents (Fig. 3A). Other limitations were a lot more prevalent in certain locations such as "staff limitations" that were mentioned three times more often in the Florida Keys compared with any other locations (Fig. 3A). 'Restoration' and 'legislative' limitations were also most mentioned in Koh Tao and the Florida Keys (Fig. 3A), which are the two locations most threatened by overpopulation and tourism pressure creating issues with land-clearing, erosion, and rubbish disposal to name a few. The feeling of disconnect from the local community was less prevalent in the Maldives, and most prevalent in the US Virgin Islands (Table D, Appendix B). The mention of ecological limitations also varied among locations, being two to three times more frequently mentioned in the Maldives than any other locations (Fig. 3A; Table D, Appendix B).

In terms of differences among respondents, 'technical limitations' were mentioned significantly more often by groups of people involved in the restoration efforts than other groups (Kruskal Wallis, chi-squared = 5.3, df = 1, p = 0.02; Fig. 3C). Responses under the themes 'management limitations', and 'staff limitations' also tended to be more frequently mentioned by groups of people involved but the trend was non-significant (Kruskal Wallis, 'management limitations': chi-squared = 2.08, df = 1, p = 0.14; 'staff limitations': chi-squared = 0.98, df = 1, p = 0.32; Fig. 3C). 'Ecological limitations' were the most mentioned limitation for the tourism industry, and it was also mentioned by over 40% of conservation professionals (Fig. 3B), indicating that these two groups of respondents are the wariest of potential negative ecological impacts of coral restoration impacts.

Less than 20% of the locals mentioned limitations of coral restoration, but of those who answered, all of them raised issues associated with 'legislative limitations'.

Finally, 'restoration limitations' were cited by respondents both directly involved in the restoration efforts and others (Kruskal Wallis, chi-squared = 1.4, df = 1, p = 0.24; Fig. 3C).

4. Discussion

This global study is the first to assess reef-users' and local community perceptions of the benefits and limitations of coral restoration across different geographic locations. Our results reveal that perceptions around coral reef restoration span far beyond ecological considerations and highlight the critical role that coral reef restoration plays in the lives of coastal communities, while acknowledging that there are important limitations to restoration efforts. By identifying how perceptions of key benefits and limitations vary across the four different projects, as well as among different types of respondents, we are able to develop insights into the importance of location-specific, as well as people-specific influences and characteristics. We discuss our most important findings.

4.1. Social outcomes out-weigh all other benefits

Socio-cultural benefits were the most frequently mentioned responses to the questions about the benefits of coral restoration. These results emphasize that the respondents' perspectives of benefits are very much geared towards socio-ecological outcomes rather than on ecological outcomes. These results also support recent claims that socio-cultural factors are central to goal-setting and assessing effectiveness of coral restoration efforts (Suding et al., 2015; Martin, 2017). Many participants valued the restoration efforts for the mere fact that they were happening, reinforcing the importance of coral reefs in people's everyday lives, especially for cultural values and well-being (e.g. Kittinger et al., 2012; Cinner et al., 2015; Marshall et al., 2017). Such results support the observation that people are aware of the vulnerability and declining status of reef ecosystems (Goldberg et al., 2016). Thus, not only do people care about the reefs for reasons beyond economic gains, but they are also concerned about the future of coral reefs. Participants also noted the importance of restoration efforts in providing hope for the future of coral reefs. This point is particularly important in view of recent movements such as #oceanoptimism (Knowlton, 2017), which moves the narrative of coral reef science beyond "doom and gloom" to encourage agency through the stewardship of reef resources.

4.1.1. Involvement in coral restoration efforts fosters stewardship

Stewardship was one of the most frequently mentioned potential benefits of coral restoration. In particular, respondents highlighted the links between stewardship and education through the restoration efforts. These findings are in line with work by Hungerford and Volk (1990) and Dean et al. (2018) who suggested that conservation education and stewardship are strongest when applied through practical experiences. Citizen participation in conservation activities also leads to greater community acceptance and faster implementation of management actions (Danielsen et al., 2010). These results also support the findings of Hesley et al. (2017) who found that the "hands-on" aspect of coral restoration promotes stewardship. However, while Hesley et al. (2017) did not find any negative ecological effect from using volunteer workforce, several respondents in this study mentioned trade-offs between education and the ecological outcomes of the restoration efforts due to the potential damage caused by the amateur, volunteer workforce.

These problems resonate with studies looking at the effectiveness of citizen science that show scientists' reluctance to trust public

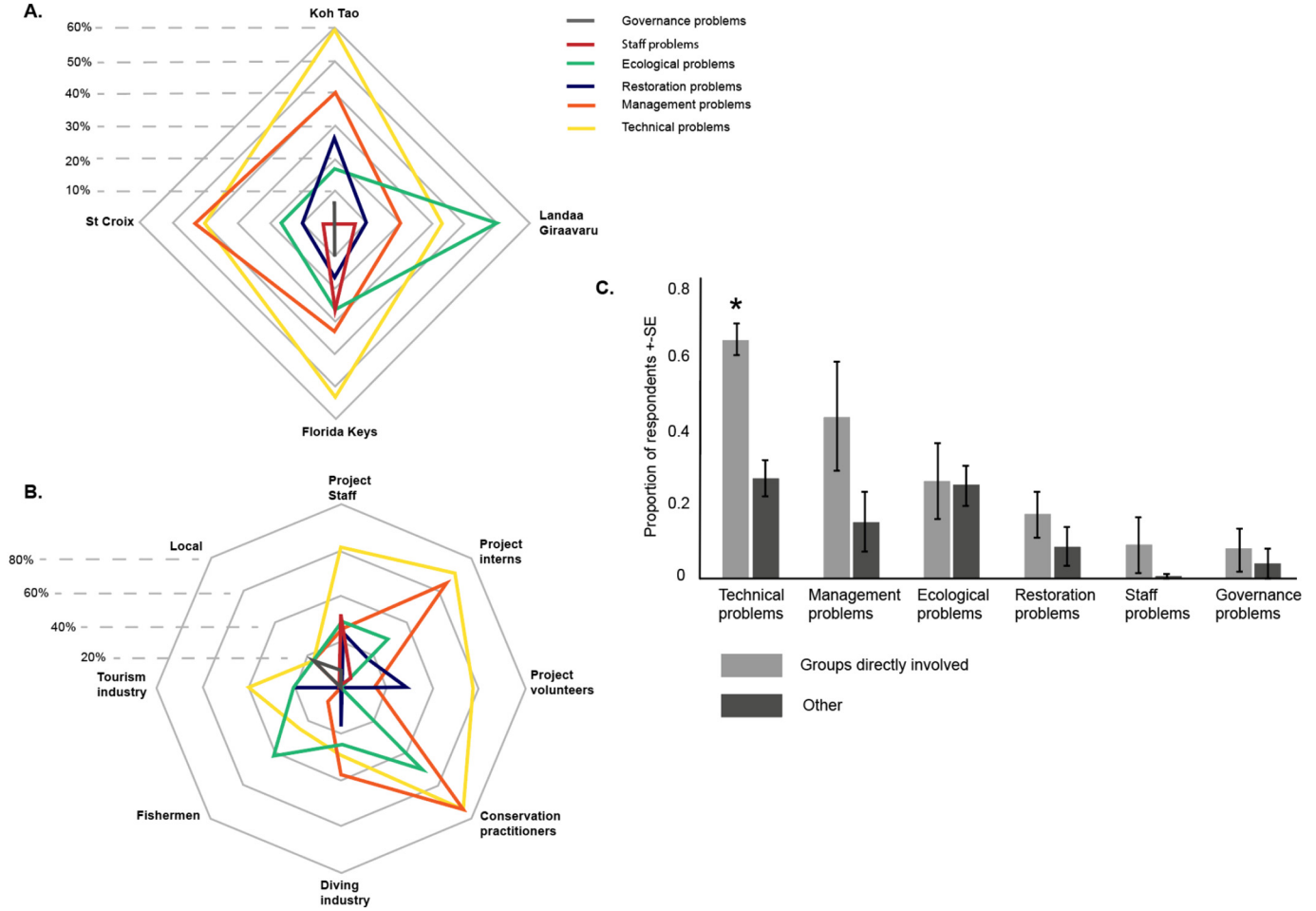

Fig. 3. Variation in the proportion of responses for themes of limitations among all four locations (n = 30 respondents per location) (A), group of stakeholders (B), and between groups of people involved directly in the efforts (n = 60 respondents) and others (n = 60 respondents) (C). * indicates significance.

involvement in data collection (Golumbic et al., 2016). When applied to coral restoration, it appears that while practitioners value public participation as critical to engage the public, promote conservation and stewardship, they do not necessarily trust the public to transplant corals back onto the reef efficiently. In citizen science, Pocock et al. (2015) have described a trade-off between biological monitoring designs that are ideal for statistical analysis and designs that allow for public participation that increase the monitoring program goals. Here, the trade-off is between having the best planting design to maximise coral growth and having more hands to scale-up the restoration efforts. This trade-off issue was brought up by restoration staff whose definition of coral restoration success is to have many corals securely attached to the reef. Given the clear importance given to socio-cultural benefits of coral restoration in this study, we suggest that goals for coral restoration should more explicitly embrace socio-cultural objectives, in order for practitioners to realise the numerous benefits of public engagement in hands-on restoration activities (Danielsen et al., 2010; Kittinger et al., 2016). For example, a higher emphasis on proper training volunteers, as shown in Hesley et al. (2017), might help overcome the trade-off between scientific design and volunteer workforce capacity and efficiency.

4.1.2. Respondents value scientifically-driven projects

Many participants also highlighted the role of science as both a benefit and limitation to restoration. The criticism that restoration projects require a more robust scientific research basis for coral-planting efforts was very prevalent in the 'identifying limitations' responses. These results echo calls from the scientific community for the need to rapidly advance coral restoration ecology research (Rinkevich, 2015). These responses also suggest that the science underpinning current restoration methodologies (e.g. Rinkevich, 2015, Johnson et al., 2011) is not necessarily used by coral restoration managers. In the responses to the benefit questions, science was linked to project appreciation, highlighting that participants valued robust scientific design for the restoration efforts. These responses also suggest that coral restoration projects can be used to enhance scientific understanding and capacity in non-research trained volunteers (Garbarino and Mason, 2016).

4.2. Ecological outcomes surpass the coral-planting phase

Responses related to ecological benefits of coral restoration were more focused on benefits at the scale of the reef ecosystem (e.g. "increased diversity of marine life", "coastline protection") than that of the coral transplants per se. These results suggest that participants perceived that measuring ecological success of coral restoration efforts requires broader considerations than the typical short-term, coral transplant focus nature of the majority of coral restoration research studies to date (Hein et al., 2017). Participants thus recognised ecological benefits at a much wider spatial scale than that of the restoration plots; this contrasts with the common criticism that the scale of impact of coral restoration is too limited to address current threats to coral reef ecosystems (e.g. Precht et al., 2005; Edwards and Gomez, 2007). For example, many responses for ecological benefits related to reef ecosystem function such as increased diversity of marine life and improved habitat protection (Fig. 1). Responses for ecological limitations also reflected larger scale ecological impacts of coral restoration with

focuses on limited diversity of the coral assemblages and potential damage to natural reefs. Altogether, the diversity of potential ecological benefits and limitations brought up by the respondents confirms that studies investigating the effectiveness of coral restoration efforts need to account for a variety of indicators and follow principles of reef resilience (Hein et al., 2017).

4.3. Local community involvement is important for the success of restoration

Low levels of local community involvement in the restoration efforts were one of the most important limitations brought up by the participants in this study. It was associated with both a lack of communication with the public and a lack of community awareness. These results suggest that the potential for education and stewardship potential through involvement in the coral restoration efforts is currently limited for local communities. The majority of project volunteers and interns were visiting tourists rather than locals. Yet, while engaging tourists is critical to spread awareness nationally and internationally, local communities are the ones who are most likely to directly benefit from the restoration actions. For example, Kittinger et al. (2016) have shown that members of the local community strongly benefited from improved well-being and increased cultural services from a reef restoration effort in Oahu, Hawaii, leading to increased community awareness of the threats to their reef-associated resources, and increased capacity for stewardship. The importance of including members of the local community in all stages of restoration efforts has also been put forward in numerous land- and watershed-based restoration project (e.g. McGinnis et al., 1999; Dhillion et al., 2004), as a way to not only improve the direct benefits of the restoration to local stakeholders, but also to use locals' knowledge to more efficiently carry out the restoration efforts. Involving volunteers from the community thus appears to be vital for creating a sense of resource ownership and maximising the potential flow-on of socio-cultural benefits.

4.4. Good governance at multiple scales can help restoration efforts

The importance of governance for coral restoration effectiveness was recognised at different scales through the responses about both benefits and limitations. Scales of governance ranged from project management to legislative considerations and impacted participants' views of the projects' logistics as well as their appreciation and support.

At the lower end of the scale, participants emphasized the importance of the ‘people factor’ in responses about the benefits and limitations of coral restoration. Within the benefits, the people factor was mostly linked to positive experience which is an integral part of citizen science project to increase participants' understanding (Garbarino and Mason, 2016), and thus stewardship and long-term commitment. Participants need to enjoy the process. On the other hand, problems associated with people were mostly referred to as ego, and miscommunication problems among staff. While these may not necessarily impact the experience of the volunteers, it can impact the logistics and effectiveness of the restoration efforts. Issues with logistics were particularly common in the limitations results recorded in this study. Such results highlight that respondents valued the inner-workings of the restoration projects as an integral part of coral restoration effectiveness, as well as the importance of having a team of staff members that were dedicated, open to adaptive change, and able to commit long-term. Restoration projects should therefore strive to be well-organized and make the process as easy as possible, in order to maximise sustained project appreciation and support.

At the upper-end of the scale, respondents both valued and criticised legislative support. In the Caribbean especially, legislative shortcomings included permit limitations that hindered the progress of the restoration efforts as well as affected the day-to day logistics of the operations. While permits are important to hold restoration practitioners accountable for their actions and ensure that proper techniques and precautions are used, more discussions between restoration practitioners and legislative bodies might be necessary to adjust permit restrictions more efficiently with the day-to-day logistics, and new scientific discoveries. Legislative problems also included limited economic support from local and national governing bodies.

4.5. Secure funding for restoration success

Economic limitations were expressed as the lack of capacity for the restoration efforts and were thus one of the most important limitations brought up by the participants. While ecological restoration is increasingly recognised by international agencies as critical to safeguard ecosystem services in the face of climate change (e.g. UN, 2016, Aronson and Alexander, 2013, Martin, 2017), funds distributed by governments are often short-term and small scale (Borgström et al., 2016). Among our case-studies, the two Caribbean-based projects (Florida Keys and Us Virgin Islands) were initially partly funded through the American Recovery and Reinvestment Act (Johnson et al., 2011) but both have also had to source additional funding from the private sector (Table A, Appendix A, Section 1). The other two projects (Maldives and Koh Tao) receive very limited funding support from their respective governments and rely on funding from interns and volunteers to sustain the restoration activities (Table A, Appendix A, Section 1). Altogether participants highlighted the limited economic capacity of the restoration efforts as a constraint to their efficacy. Securing long-term funding thus appears to be an essential consideration to the planning of successful coral restoration efforts. In particular, if the restoration goals are focused on socio-economic outcomes, then managers should intently consider funding targeting the training of volunteers and local community participants to both scuba-diving and restoration skills as part of their grant application.

4.6. Perceptions varied among locations and groups of respondents

Responses for both benefits and limitations varied among locations and group of respondents. Variations among locations highlight the context-specificity of people's perception of coral restoration success. While the importance of context has been demonstrated for the ecological outcomes of coral restoration (Ladd et al., 2018), this study is the first to demonstrate context-specificity for socio-cultural outcomes.

The feeling of disconnect from the local community was one that particularly varied among the four locations, being less prevalent in the Maldives where locals are employed by the hotel through an apprenticeship program to work with the restoration project (Hein et al. 2018 (in press)). It was most prevalent in the US Virgin Island where local islanders are disconnected from the ocean resources. Ecological limitations were also most frequently mentioned in the Maldives, which can probably be attributed to the mass coral bleaching event of 2016 that severely affected the Maldives at the time of the survey.

Responses also varied among different groups of respondents, especially between groups of people involved first-hand in the restoration efforts and others. In particular, socio-cultural benefits were most often mentioned by groups of people involved first-hand suggesting highlighting that the objectives of coral restoration programs generally span beyond ecological outcomes alone (Hein et al., 2017). The lower emphasis on economic benefits by project staff and conservation professionals also suggests that economic benefits are not the primary concern of people directly involved in the restoration efforts (i.e. they are not doing this for money). On the other hand, other themes were also mentioned as frequently between people involved and others. That was true for responses within the theme “restoration limitations” for example, suggesting widespread uncertainty about the efficacy of coral restoration as a reef management strategy among stakeholders.

Altogether, these differences among location and groups of

respondents suggest that perceptions of restoration effectiveness are subjective, and therefore that the meaning of success is likely to be context-specific. These are important considerations for restoration managers, as managing for stakeholders' perception of success is crucial to ensure long-term sustained support (Bennett et al., 2016; Sterling et al., 2017). Future research should investigate the variation in perceptions among stakeholders more specifically.

5. Conclusion

Respondents across all four locations provided a very rich range of responses to both benefits and limitations of coral restoration. These covered all four pillars of sustainability: ecological outcomes, social outcomes, governance outcomes, and economic outcomes (Valentin and Spangenberg, 2000; Spangenberg, 2004), suggesting that coral restoration is rooted in sustainability principles and needs to acknowledge and account for factors beyond ecological considerations (Ammar, 2009; Suding et al., 2015; Hein et al., 2017). While we identify several important limitations of coral reef restoration, particularly around amateur workforces, our results suggest that coral restoration can be used as a powerful conservation education tool to promote stewardship and enhance coral reef conservation management strategies. Through embracing the socio-cultural dimensions of coral restoration in goal setting, efficient monitoring of ecological success, improved management and logistics of the day to day practices, improved capacity for local community involvement, and secured long-term funding, coral restoration can be a powerful tool to support resilience and provide hope for the future of coral reefs and the many important benefits associated with them.

Acknowledgements

This research was supported by the College of Science and Engineering at James Cook University and the Australian Research Council Centre of Excellence for Coral Reef Studies. Data was collected following requirement under JCU Human Ethics permit H6539 and the Coral Restoration Foundation Research policies (ID CRF-2016-23). We also thank P. Urgell, C. Scott, F. Couture, S. Stradal, T. Le Berre, K. Ripple, J. Levy, R. Willis, L. Terry, and K. Lewis for assistance in the data collection as well as T.J. Chase for useful comments and improvements to the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2018.11.014.

References

Alvarez-Filip, L., Dulvy, N.K., Gill, J.A., Côté, I.M., Watkinson, A.R., 2009. Flattening of Caribbean coral reefs: region-wide declines in architectural complexity. Proc. Biol. Sci. 276 (1669), 3019–3025. https://doi.org/10.1098/rspb.2009.0339.

Ammar, M.S.A., 2009. Coral reef restoration and artificial reef management, future and economic. Open Environ. Eng. J. 2, 37–49. https://doi.org/10.2174/1874829500902010037.

Anthony, K., Bay, L.K., Costanza, R., ... Walshe, T., 2017. New interventions are needed to save coral reefs. Nat. Ecol. Evol. 1 (10), 1420–1422. https://doi.org/10.1038/s41559-017-0313-5.

Aronson, J., Alexander, S., 2013. Ecosystem restoration is now a global priority: time to roll up our sleeves. Restor. Ecol. 21 (3), 293–296. https://doi.org/10.1111/rec.12011.

Assessment, T M E, 2005. Ecosystems and Human Well-being Ecosystems and Human Well-being.

Bayraktarov, E., Saunders, M.I., Abdullah, S., ... Lovelock, C.E., 2015. The cost and feasibility of marine coastal restoration. Ecol. Appl. 15–1077, 1. https://doi.org/10.1890/15-1077.1.

Bennett, N.J., Roth, R., Klain, S.C., ... Wyborn, C., 2016. Conservation social science: understanding and integrating human dimensions to improve conservation. Biol. Conserv. 205, 93–108. https://doi.org/10.1016/j.biocon.2016.10.006.

Berkes, F., Colding, J., Folke, C., 2003. Navigating Social–ecological Systems: Building Resilience for Complexity and Change. vol. 119 Cambridge University Presshttps://doi.org/10.1016/j.biocon.2004.01.010.

Borgström, S., Zachrisson, A., Eckerberg, K., 2016. Land use policy funding ecological restoration policy in practice — patterns of short-termism and regional biases. Land Use Policy 52, 439–453. https://doi.org/10.1016/j.landusepol.2016.01.004.

Both, C., Bouwhuis, S., Lessells, C.M., Visser, M.E., 2006. Climate change and population declines in a long-distance migratory bird. Nature 441 (1), 81–83. https://doi.org/10.1038/nature04539.

Brodie, J.E., Kroon, B., Schaffelke, B., ... Davis, A.M., 2012. Terrestrial pollutant run-off to the Great Barrier Reef: an update of issues, priorities and management responses. Mar. Pollut. Bull. 65, 81–100.

Cinner, J.E., Pratchett, M.S., Graham, N.A.J., ... Williamson, D.H., 2015. A framework for understanding climate change impacts on coral reef social–ecological systems. Reg. Environ. Chang. https://doi.org/10.1007/s10113-015-0832-z. (July).

Cumming, G.S., Barnes, G., Perz, S., ... Van Holt, T., 2005. An Exploratory Framework for the Empirical Measurement of Resilience. pp. 975–987. https://doi.org/10.1007/s10021-005-0129-z.

Danielsen, F., Burgess, N.D., Jensen, P.M., Pirhofer-Walzl, K., 2010. Environmental monitoring: the scale and speed of implementation varies according to the degree of peoples involvement. J. Appl. Ecol. 47 (6), 1166–1168. https://doi.org/10.1111/j.1365-2664.2010.01874.x.

Darling, E.S., Côté, I.M., 2018. Seeking resilience in marine ecosystems. Science 359 (6379), 986–987. https://doi.org/10.1126/science.aas9852.

Dean, A.J., Church, E.K., Loder, J., Fielding, K.S., Wilson, K.A., 2018. How do marine and coastal citizen science experiences foster environmental engagement? J. Environ. Manag. 213, 409–416. https://doi.org/10.1016/j.jenvman.2018.02.080.

De'ath, G., Fabricius, K.E., Sweatman, H., Puotinen, M., 2012. From the cover: the 27-year decline of coral cover on the Great Barrier Reef and its causes. Proc. Natl. Acad. Sci. 109 (44), 17995–17999. https://doi.org/10.1073/pnas.1208909109.

Dhillion, S.S., Aguilar-Støen, M., Camargo-Ricalde, S.L., 2004. Integrative ecological restoration and the involvement of local communities in the Tehuacán-Cuicatlán Valley, Mexico. Environ. Conserv. 31 (1), 1–3. https://doi.org/10.1017/S0376892904001043.

Eakin, C.M., Liu, G., Gomez, A.M., De La Cour, J.L., ... Strong, A.E., 2016. Global Coral Bleaching 2014–2017? Status and an Appeal for Observations. 43. Reef Encounter, pp. 20–26 (31(1)).

Edwards, A.J., Gomez, E.D., 2007. Reef restoration concepts & guidelines: making sensible management choices in the face of uncertainty. Coral Reef Targeted Research & Capacity Building for Management Program St. Lucia, Queensland, Australia.

Elwood, E.R., Crimmins, T.M., Miller-Rushing, A.J., 2017. Citizen science and conservation: recommendations for a rapidly moving field. Biol. Conserv. 208, 1–4.

Folke, C., 2006. Resilience: the emergence of a perspective for social – ecological systems analyses. Glob. Environ. Chang. 16, 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002.

Frey, J.B., Berkes, F., 2014. Can partnerships and community-based conservation reverse the decline of coral reef social-ecological systems? Int. J. Commons 8 (1), 26–46.

Garbarino, J., Mason, C.E., 2016. The power of engaging citizen scientists for scientific progress. J. Microbiol. Biol. Educ. 17 (1), 7–12.

Glaser, M., 2006. The social dimension in ecosystem management: strengths and weaknesses of human-nature mind maps. Res. Hum. Ecol. 13 (2), 122–142.

Goldberg, J., Marshall, N., Birtles, A., ... Visperas, B., 2016. Climate change, the Great Barrier Reef and the response of Australians. Palgrave Commun. 2, 15046. https://doi.org/10.1057/palcomms.2015.46.

Golumbic, Y.N., Orr, D., Baram-Tsabari, A., Fishbein, B., 2016. Between vision and reality: a case study of scientists' views on citizen science. Citizen Sci. Theory Pract. 2 (1), 1–13. https://doi.org/10.5334/cstp.53.

Haapkylä, J., Unsworth, R.K.F., Flavell, M., Willis, B.L., 2011. Seasonal rainfall and runoff promote coral disease on the Great Barrier Reef. PLoS One 6 (2), e16893.

Hein, M.Y., Willis, B.L., Beeden, R., Birtles, A., 2017. The need for broader ecological and socioeconomic tools to evaluate the effectiveness of coral restoration programs. Restor. Ecol. 25 (6). https://doi.org/10.1111/rec.12580.

Hein, M.Y., Couture, F., Scott, C., 2018. Ecotourism and coral restoration: case studies from Thailand and the Maldives. In: Prideaux, Bruce, Pabel, Anja (Eds.), Coral Reefs: Tourism, Conservation and Management, 1st edition. Routledge's Earthscan Oceans Series Abingdon-on-Thames (in press).

Hesley, D., Burdeno, D., Drury, C., Schopmeyer, S., Lirman, D., 2017. Citizen science benefits coral reef restoration activities. J. Nat. Conserv. 40, 94–99.

Hoegh-Guldberg, O., Bruno, J.F., 2010. The impact of climate change on the. Science 328 (June), 1523–1528.

Hughes, T.P., Graham, N. a J., Jackson, J.B.C., Mumby, P.J., Steneck, R.S., 2010. Rising to the challenge of sustaining coral reef resilience. Trends Ecol. Evol. 25 (11), 633–642. https://doi.org/10.1016/j.tree.2010.07.011.

Hughes, T.P., Kerry, J.T., Álvarez-Noriega, ... Wilson, S.K., 2017. Global warming and recurrent mass bleaching of corals. Nature 543 (7645), 373–377. https://doi.org/10.1038/nature21707.

Hughes, T.P., Anderson, K.D., Connolly, ... Wilson, S.K., 2018. Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. Science 359 (6371), 80–83. https://doi.org/10.1126/science.aan8048.

Hungerford, H.R., Volk, T.L., 1990. Changing learner behavior through environmental education. J. Environ. Educ. 21 (3), 8–21. https://doi.org/10.1080/00958964.1990.10753743.

Jackson, J.B.C., Donovan, M.K., Cramer, K.L., Lam, V., Lam, W., 2014. Status and Trends of Caribbean Coral Reefs: 1970–2012. Global Coral Reef Monitoring Network, IUCN, Gland, Switzerland, pp. 306.

Jellinek, S., Rumpff, L., Driscoll, D.A., Parris, K.M., Wintle, B.A., 2014. Modelling the benefits of habitat restoration in socio-ecological systems. Biol. Conserv. 169, 60–67. https://doi.org/10.1016/j.biocon.2013.10.023.

Johnson, M.E., Lustic, C., Bartels, E., ... Schopmeyer, S.A., 2011. Caribbean Acropora Restoration Guide: Best-practices for Propagation and Population Enhancement.
Kittinger, J.N., Finkbeiner, E.M., Glazier, E.W., Crowder, L.B., 2012. Human Dimensions of Coral Reef Social-ecological Systems. 17(4)https://doi.org/10.5751/ES-05115-170417.
Kittinger, J.N., Bambico, T.M., Minton, D., ... Glazier, E.W., 2016. Restoring ecosystems, restoring community: socioeconomic and cultural dimensions of a community-based coral reef restoration project. Reg. Environ. Chang. 16 (2), 301–313. https://doi.org/10.1007/s10113-013-0572-x.
Knowlton, N., 2017. Doom and gloom won't save the world. Nature 544 (7650), 271. https://doi.org/10.1038/544271a.
Knowlton, N., Jackson, J.B.C., 2008. Shifting baselines, local impacts, and global change on coral reefs. PLoS Biol. 6 (2), 0215–0220. https://doi.org/10.1371/journal.pbio.0060054.
Ladd, M.C., Miller, M.W., Hunt, J.H., Sharp, W.C., Burkepile, D.E., 2018. Harnessing ecological processes to facilitate coral restoration. Front. Ecol. Environ. 16 (4), 239–247.
Marshall, N.A., Marshall, P.A., 2007. Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. Ecol. Soc. 12 (1) (https://doi.org/1).
Marshall, N.A., Tobin, R.C., Marshall, P.A., Gooch, M., Hobday, A.J., 2013. Social vulnerability of marine resource users to extreme weather events. Ecosystems 16, 797–809.
Marshall, N.A., Curnock, M.I., Goldberg, J., Gooch, M., ... Tobin, R.C., 2017. The dependency of people on the Great Barrier Reef, Australia. Coast. Manag. 45 (6), 505–518. https://doi.org/10.1080/08920753.2017.1373454.
Martin, D.M., 2017. Ecological restoration should be redefined for the twenty-first century. Restor. Ecol. 25 (5), 668–673. https://doi.org/10.1111/rec.12554.
Maynard, J., van Hooidonk, R., Eakin, ... Harvell, C.D., 2015. Projections of climate conditions that increase coral disease susceptibility and pathogen abundance and virulence. Nat. Clim. Chang. 5 (7), 688–694. https://doi.org/10.1038/nclimate2625.
Maynard, J.A., Marshall, P.A., ... Tamelander, J., 2017. Coral Reef Resilience for Decision Support. UN Environment, Nairobi, Kenya.
McCulloch, M., Fallon, S., Wyndham, T., Barnes, D., 2003. Coral record of increased sediment influx to the inner Great Barrier Reef since European settlement. Nature 421, 727–730.
McGinnis, M., Woolley, J., Gamman, J., 1999. Bioregional conflict resolution: rebuilding community in watershed planning and organizing. Environ. Manag. 24 (1), 1:12.
Moberg, F., Folke, C., 1999. Ecological goods and services of coral reef ecosystems. Ecol. Econ. 29 (2), 215–233. https://doi.org/10.1016/S0921-8009(99)00009-9.
Mumby, P.J., Hastings, A., Edwards, H.J., 2007. Thresholds and the resilience of Caribbean coral reefs. Nature 450 (7166), 98–101. https://doi.org/10.1038/nature06252.
Perring, M.P., Standish, R.J., Price, J.N., ... Hobbs, R.J., 2015. Advances in restoration ecology: rising to the challenges of the coming decades. Ecosphere 6 (8). https://doi.org/10.1890/ES15-00121.1.
Pocock, M.J.O., Newson, S.E., Henderson, ... Roy, D.B., 2015. Developing and enhancing biodiversity monitoring programmes: a collaborative assessment of priorities. J. Appl. Ecol. 52 (3), 686–695. https://doi.org/10.1111/1365-2664.12423.
Precht, W.F., Aronson, R.B., Miller, S.L., Keller, B.D., Causey, B.D., 2005. The folly of coral restoration programs following natural disturbances in the Florida Keys National Marine Sanctuary. Ecol. Restor. 23 (1), 24–28. https://doi.org/10.3368/er.23.1.24.
Rinkevich, B., 2015. Novel tradable instruments in the conservation of coral reefs, based on the coral gardening concept for reef restoration. J. Environ. Manag. 162, 199–205. https://doi.org/10.1016/j.jenvman.2015.07.028.
Spangenberg, J.H., 2004. Sustainability and growth: criteria, indicators, policies. Sustain. Dev. 12, 74–86.
Sterling, E.J., Betley, E., Sigouin, A., ... Filardi, C., 2017. Assessing the evidence for stakeholder engagement in biodiversity conservation. Biol. Conserv. 209, 159–171.
Suding, K., Higgs, E., Palmer, M., ... Schwartz, K.Z.S., 2015. Committing to ecological restoration. Science 348 (6235), 638–640. https://doi.org/10.1126/science.aaa4216.
Tulloch, A.I.T., Possingham, H.P., Joseph, L.N., Szabo, J., Martin, T.G., 2013. Realising the full potential of citizen science monitoring programs. Biol. Conserv. 165, 128–138. https://doi.org/10.1016/j.biocon.2013.05.025.
UN, 2016. Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development. A/RES/71/313 E/CN.3/2018/2. https://unstats.un.org/sdgs/indicators/indicators-list/.
Valentin, A., Spangenberg, J.H., 2000. A guide to community sustainability indicators. Environ. Impact Assess. Rev. 20 (3), 381–392. https://doi.org/10.1016/S0195-9255(00)00049-4.
Walther, G.R., Post, E., Convey, P., ... Bairlein, F., 2002. Ecological responses to recent climate change. Nature 416 (6879), 389–395. https://doi.org/10.1038/416389a.
Wolff, N.H., Mumby, P.J., Devlin, M., Anthony, K.R.N., 2018. Vulnerability of the Great Barrier Reef to climate change and local pressures. Glob. Chang. Biol. https://doi.org/10.1111/gcb.14043. (October 2017).
Young, T., 2000. Restoration ecology and conservation biology. Biol. Conserv. 92, 73–83. https://doi.org/10.3368/er.18.4.243.